MAGNETOSTATIC VOLUME WAVE RESONATORS

J.P. CASTERA
THOMSON-CSF - Laboratoire Central de Recherches
Domaine de Corbeville - 91401 Orsay (France)

ABSTRACT

The purpose of this paper is to report new advances about magnetostatic volume wave (MSVW) resonators. The waves have been propagated in an epitaxial yttrium iron garnet (YIG) film at GHz frequencies. These devices use periodic etched groove gratings as distributed reflectors for MSVW. The design and experimental data about a magnetostatic forward volume wave (MSFVW) and a magnetostatic backward volume wave (MSBVW) resonators are given. The frequency response, the Q value and the tunability are reported and compared to those obtained with magnetostatic surface wave (MSSW) resonators.

INTRODUCTION

Magnetostatic waves can be propagated in yttrium-iron garnet (YIG) film deposited on a gadolinium-gallium garnet (GGG) substrate up to 20 GHz. Microwave components for signal processing can be performed with a microminiature structure using the propagation of magnetostatic waves. One-port and two - port magnetostatic surface wave resonators have been fabricated and tested[1,2,3]. These devices use periodic etched groove gratings as frequency selective reflectors and microstrip transducers for coupling. The objective of this paper is to report for the first time to our knowledge results obtained between 2 and 4 GHz with MSFVW and MSBVW resonators.

2 - PORT RESONATOR

A periodic grating reflects the MSW. The amplitude reflection and transmission coefficients are related to the number of reflecting sections by the expressions :

$$|R| = \frac{Z^{2N} - 1}{Z^{2N} + 1} \qquad |T| = \frac{2\,Z^{N}}{Z^{2N}+1} \qquad (1)$$

where $Z = Z_o/Z_1$ is the wave-impedance ratio of the unperturbed to perturbed sections of the array and N the number of periods in the whole array. The wave impedance is proportionnal to the YIG film thickness. The resonator consists of a pair of wavelength selective periodic gratings separated by a non-perturbed path as shown in figure 1. d is the thickness of the YIG film,

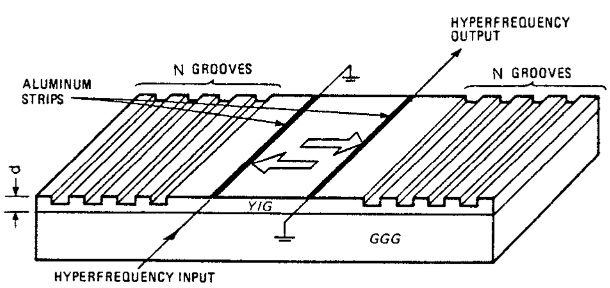

Fig.1 - 2-Port MSW resonator schematic.

h is the groove depth, D the distance between the gratings and N the number of grooves per array. For the experiments, 75 µm wide grooves, 4 mm long and separated by 75 µm were ion beam milled in YIG films. Two devices have been realized. Their characteristics are summarized in Table 1. The

resonator	d (µm)	h (µm)	D (mm)	N
A	10	0.6	3	66
B	8	0.28	3	56

Table 1. - Characteristics of resonators A and B.

launching and receiving aluminum microstrip couplers are 30 µm wide, 6 mm long and separated over 3 mm. For resonator A, the transducers are deposited directly on the YIG film while for resonator B, they are etched on an alumina substrate and the YIG film placed in contact with the alumina. From experiments with a lot of MSSW resonators, we have deduced the empiric following relationship giving the effective distance Le of a resonator as a function of D, λ (wavelength of MSSW) and ε ($\varepsilon = (Z_o - Z_1)/Z_o$) :

$$Le = D + \frac{\lambda}{a\,\varepsilon} \quad \text{where } a \simeq 1.3 \qquad (2)$$

The inverse Q value of a grooved Fabry - Perot resonator is related to the various elementary Q by the usual sum of inverse elementary Q[4]. Only the Q due to the propagation losses, Q_1, and that one related to the radiation associated with leakage through the imperfectly reflecting gratings, Q_r, are considered. Q_1 may be expressed as follows :

$$Q_1 = 0.35 \quad 10^{-6}\,\frac{f}{\Delta H} \qquad (3)$$

where f is the frequency of magnetostatic waves and ΔH the full linewidth at half power points. Q_r can be expressed in the same form as that for an electromagnetic Fabry - Perot cavity :

$$Q_r = \frac{2\pi Le}{\lambda\ (1 - R^4)} \qquad (4)$$

where Le satisfies eq.(2), λ is the wavelength and R the amplitude reflection coefficient given by eq.(1). The unloaded Q is given by :

$$Q^{-1} = Q_1^{-1} + Q_r^{-1} \qquad (5)$$

Figure 2 shows the variation of Q with h/d. In this example, N = 56, λ = 300 µm, D = 3 mm, f = 2.4 GHz and ΔH = 0.2 Oe. We can see on this figure that the gratings need deep grooves to achieve a high Q value, typically h/d > 0.07 to obtain Q > 4000. In this calculation, we have not taken into account the variations of ΔH with frequency.

MSFVW resonators : Resonators A and B have been tested. The magnetic field is applied perpendicular to the plane of the films. The frequency response characteristics of these devices are shown in figure 3. The response of resonator A, for which h/d = 0.060, presents several modes 2.5 MHz distant. In this example, the applied magnetic field H = 2410 Oe and the center frequency is equal to 2400 MHz. The mode spacing may be calculated from the following relation :

$$\Delta f = \frac{vg}{2\ Le} \qquad (6)$$

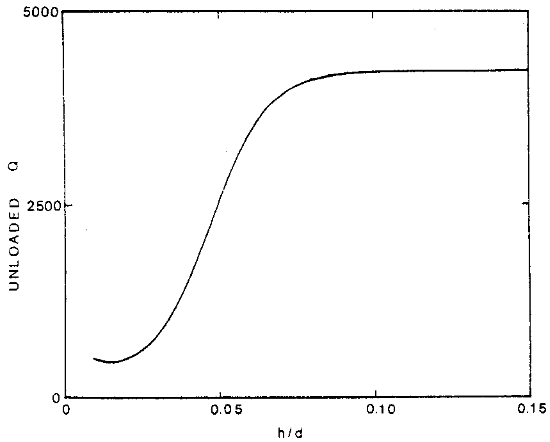

Fig. 2 - Calculated unloaded Q versus h/d with $F = 2.4$ GHz, $\Delta H = 0.2$ Oe, $D = 3$ mm, $\lambda = 300$ µm and $N = 56$.

where Le is given by eq. (2) and vg is the group velocity of MSFVW :

$$vg = \frac{2\pi\alpha}{\frac{d\alpha}{df}\left\{k + \frac{2}{d(\alpha^2+1)}\right\}} \quad (7)$$

where :

$$\alpha = \left[\frac{H\,Hi - (f/\gamma)^2}{(f/\gamma)^2 - Hi^2}\right]^{1/2}$$

$$Hi = H - 4\pi M$$

$$k = \frac{2}{d}\,\frac{1}{\alpha}\ \text{arc tg}\,(1/\alpha)$$

$$\frac{d\alpha}{df} = -\frac{4\pi M\,Hi\,f}{\gamma^2\,\alpha\,\left[(f/\gamma)^2 - Hi^2\right]^2}$$

H is the applied magnetic field, $4\pi M$ the saturation magnetization ($4\pi M = 1750$ Oe), γ the gyromagnetic ratio ($\gamma = 2.8$ MHz/Oe), d the thickness of the YIG film and f the frequency of MSFVW. With the experimental values of H and f, we obtain from eq.(6) $\Delta f = 2.59$ MHz. The agreement is good between this calculated result and the experimental value given before. The difference may be due to the approximation made in eq. (6) where we have neglected the variations of vg in the arrays. Because of the low value of mode spacing for this cavity, it is not possible to separate the different modes and to measure the loaded Q. The insertion losses are 12 dB, value similar to that obtained with MSSW. We can see on the frequency response of resonator A the attenuation notches produced by the coupling of MSFVW with resonant exchange dominated spin wave modes as previously described by J.D. Adam et al[5]. For resonator B, the response is quite different as shown in figure 3.The value of h/d for this device is lower than for device A. The useful grating length is then larger for B than for A. That gives a narrower MSFVW stopband for B and a single mode is selected. The loaded Q at 2.2 GHz is equal to 550. The frequency response of this cavity does not present the absorption notches as described before. The main reason is that MSW mode conversion to normally propagating spin wave modes by the bias field discontinuity occuring at the etched grooves is reduced by a lower h/d than in the case of resonator A.

Fig. 3 - Experimental MSFVW insertion loss versus frequency for resonators A and B.

MSBVW resonator : The same devices have been experimented with MSBVW. In this experiment, the magnetic field is applied parallel to the propagation direction of the waves. The frequency response for resonators A and B are shown in figure 4. The insertion losses, 19 dB forA and 24 dB for B, are more important with MSBVW than with MSFVW. The loaded Q at 4.210 GHz for resonator A is 840 and 870 at 4.350 GHz for resonator B. The frequency responses do not present attenuation notches due to the coupling between the magnetostatic waves and spin wave modes. This is consistent with the results obtained by J.C. Adam et al[5] showing that there is no coupling between spin wave modes and MSBVW.

Fig. 4 - MSBVW response characteristics for resonators A and B.

In the case of MSFVW, the frequency responses of resonators A and B are tunable by bias field adjustment over several gigahertz. For MSBVW, this response is also tunable over more than an octave but it is limited to about 2.7 GHz in the lower frequencies. We explain this fact by the demagnetizing field occuring at the grooves. The magnetic field necessary to saturate the film is then higher than for a non - etched film and the waves appear at higher frequencies.

Comparison with MSSW resonators : Resonators A and B have been tested with MSSW. Table 2 shows a summary of the

	Insertion Losses (dB)		Loaded Q	
	A	B	A	B
MSSW	9	13	665	314
MSFVW	12	13	/	550
MSBVW	19	24	830	870

Table 2 - Comparison of measured insertion losses and Q values with MSSW, MSFVW and MSBVW for resonators A and B.

results for insertion losses and Q values. The loaded Q is greater for MSVW than for MSSW. The fact that the volume waves are less sensitive to the surface defects of the YIG film may explain this result. Moreover, MSSW and MSVW present two main differences :

- The MSSW are located near the YIG - air interface for a given direction of the applied magnetic field and at the YIG- substrate interface for the field in the other direction. This fact is used to decouple the transducers from the resonator for the off-resonance transmission. It is not the same for MSVW and consequently the off-resonance transmission for these waves is larger than for MSSW.
- MSSW typically saturate for an input CW signal of about - 10 dBm. On the other hand, MSVW allow operation at ≃ 10 dBm input power levels. This characteristic is very important for the applications.

In conclusion, grooved Fabry - Perot type resonator using the propagation of magnetostatic forward volume waves and magnetostatic backward volume waves have been tested. Q values greater than 800 have been obtained. These devices allow operation at high power levels (≃ 10 dBm) compared with magnetostatic surface wave resonators. But the off - resonance transmission is larger than for MSSW resonators. Moreover the tunability is of the same order as for MSSW resonators, typically several gigahertz.

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REFERENCES

1 - J.H. Collins, et al, Proc. IEEE Lett., 65, 1090-1092, 1977

2 - J.H. Collins, et al, 1977 Ultrasonics Symp. Proc. IEEE Cat. No 77 CH 1264 1 SU, 541-552, 1977.

3 - J.P. Castéra and P. Hartemann, Proceedings of the 8th European Microwave Conference, pp.658-662, 1978.

4 - R.C.M. Li, J.A. Alusow and R.C. Williamson, 1975 Ultrasonics Symposium Proceedings, IEEE cat. ≠ 75 CHO 994 - 4 SU.

5 - J.D. Adam, T.W. O'Keeffe and R.W. Patterson, 24th annual conference on magnetism and magnetic materials, Nov. 14-18, 1978, Cleveland, Ohio.